

Energy Consumption Program—A Computer Model Simulating Energy Loads in Buildings

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The JPL Energy Consumption Computer Program has been primarily developed as a useful tool in the on-going building modification studies in the DSN energy conservation project. The program simulates building heating and cooling loads and computes thermal and electric energy consumption and cost. It is a very low-cost code compared with other sophisticated programs such as NECAP (costs 1/200 of NECAP) or with other commercial ones such as ECUBE, TRACE, etc. The accuracy of computations are not sacrificed, however, since the results lie within $\pm 10\%$ margin compared to those read from energy meters. The program is carefully structured to reduce both user's time and running cost by asking minimum information from the user and reducing many internal time-consuming computational loops. Many unique features were added to handle two-level electronics control rooms not found in any other program.

I. Introduction

It is commonly conceived that buildings can be designed for minimum energy consumption if their thermal insulation is increased, window air leakage and lighting levels decreased, shading devices properly installed, heating and cooling equipment adequately designed and maintained, and their capacity fully utilized. These energy saving ideas and others should be coupled before implementation with cost of add-on materials, maintenance and operation costs, conforming to building codes, life styles, esthetics, etc. Design and operation of heating and cooling systems based upon conventional steady-state peak summer hour or peak winter hour, usually results in over-sizing of equipment and consequently overheating or overcooling of the space to be controlled. Over-designed systems, while they are occupying more space, always operate at lower efficiency and, in turn, require more energy to function.

The only effective way to study and design heating or cooling systems to minimize their energy consumption is to simulate the building thermal performance as accurately as possible. With the advent of high-speed digital computers, the above simulation process on an hourly basis for a full year and summation over many zones or buildings became feasible. In the last ten years, several thermal energy loads programs have been developed which vary in cost, availability to the user, program structure and assumptions used in computations, as indicated in Refs. (1), (2). Most of these programs, whether they are public or proprietary, are applicable to new buildings or to add-on or retrofit systems. The user may access these programs by: (1) purchasing public source codes, (2) through time-sharing by input data only to proprietary source codes or (3) input data only to the developer when dealing with complete proprietary codes. The disadvantages to the user in types (2) and (3) above are the lack of awareness about assumptions

and limitations made by the developer and the inability of the user to modify or improve the codes. Proprietary programs are usually written by architect/engineering consultants, heating, ventilation and air conditioning (HVAC) equipment manufacturers or utility companies. The cost to the user is usually included in their service.

As part of the Deep Space Network (DSN) energy conservation project (an extension of the old Goldstone Energy Project), approximately 23 buildings out of 50 were identified by a first phase study as major energy consumption buildings and were further put under investigation for a second building modification study. Both studies and energy-saving recommendations were made by architect/engineer firms in cooperation with the DSN engineering section. Furthermore, several energy-saving suggestions and proposals regarding building modifications have been presented by DSS Operations technicians and engineers as part of the personnel Energy Conservation, Awareness and Recognition Program, (ECARP). It has therefore become essential for economic and technical reasons to develop an in-house tool for assessment and evaluation of all building modifications.

To accomplish the task of finding this tool, a survey was made among approximately 14 codes for heating and cooling load simulation. The major programs among them are: (1) ECUBE 75, which was developed by the American Gas Association, (2) NBSLD, the National Bureau of Standards load calculation program, (3) NECAP, the comprehensive and expensive NASA's energy cost analysis program, (4) TRACE, the Trane Air Conditioning and Economics Program and (5) USPS, the United States Postal Services program developed by the General American Transportation Corp. Two architect/engineering firms, Keller and Gannon Consulting Engineers and Burns and Roe Inc., used ECUBE 75 in the initial phases of the building modification study.

Most of these programs tend to be of the same structure and are divided into four parts: (1) calculation of space (zone) loads for heating and cooling, (2) simulation of fan-coil (air handler) systems to meet above space loads, (3) simulation of primary equipment such as chillers, boilers, engines or heat pumps and (4) economic analysis of owning and operating HVAC systems. The Energy Consumption Program (ECP) is, however, mainly divided into the first three parts above, and the fourth part is replaced by the cost of thermal and electric energy as will be discussed further in the following sections.

II. Program Description

The calculation of energy requirements for heating or cooling in any building involves three major consecutive steps.

First, the heat loss or heat gain to the space which is heated or cooled is computed. Second, the heating or cooling loads imposed on the heating or cooling coils inside the air-handlers are determined. Third, the energy input to all of the primary equipment or components constituting the air-conditioning system, such as compressors, heat pumps, boilers, engines, etc., is calculated. Each of these calculation steps may be carried out with various degrees of complexity and sophistication if more accuracy or refinement are required. The following describe the methodology used in each of the programming procedure and calculation steps.

A. Weather

Under this heading, only outside air dry-bulb temperature, cloud cover factors and wind speed are needed. For the outside air dry-bulb temperature, twelve representative days (one for each month) per year indicate the year's weather pattern. For each of these representative days, 24-h values of dry-bulb temperatures are needed. Cloud cover factors are determined by the ratio of actually accumulated daily solar energy incident on the location to that accumulated theoretically by ASHRAE model (Ref. 3). If no solar irradiation data were available, the cloud-cover factor would be estimated from past experience by the percentage of clear sky area on the selected representative day of the month. Twelve cloud-cover factors are required, corresponding to 12 months of the year. Wind speeds are required hourly for a complete day representing the yearly average wind speed in the location. All the weather data above represents the minimum information needed in order to achieve reliable results.

B. Transmission Loads Through Walls and Roofs

Some methods have been developed in the past such as "degree-days" method or "bin" method for proportioning the design load to provide hourly loads, and were found unacceptable with their gross approximations. On the other hand, sophisticated and time-consuming methods, such as using the transfer functions or response factors, are unfortunately very expensive and cannot be justified on the basis of the random changes of many other parameters in the system. This means that it is illogical to increase the accuracy of only one of the many sources of heating/cooling loads (i.e., the heat transmission through walls and roofs) while the other sources are subject to random changes with very large errors.

The methodology used in ECP is the Sol-air temperature method or total equivalent temperature method (TETD) as described in Refs. (3) and (4). It is a comprehensive yet easy to apply method. In the TETD method, the effects of outside air temperature and solar radiation intensity are combined into a single quantity. Walls and roofs are assumed homogenous with constant material properties that are determined in

advance by a special procedure. A special subroutine is written to determine analytically all the steady-state and transient heat transfer coefficients together with the phase angles needed to run the heat transmission computations.

C. Solar Heat Gain

Solar radiation values have been included in a subroutine using the well-known ASHRAE model described in Ref. (3) with ground reflectivity assumed at 0.2. The cloud-cover factors will modify these radiation values at a given month, day, or hour to yield the solar radiation values specific to the location. This procedure was found to be effective in reducing the solar radiation data or cloud data to be processed by the user.

D. Infiltration/Exfiltration Loads

The air change method was preferred over the crack method. For any space under consideration, the effect of repetitive opening and closing of doors or windows, leakage of outside air to or from the space through cracks, clearances, etc., is averaged by assuming an outside air change rate of 1.2 changes per hour. The heat loss or gain to the space is calculated accordingly, assuming quasi-steady-state conditions.

E. Internal Heat Load Profile

Only sensible heat gain is considered in ECP since the latent loads are often less than 10% of the total heat gain. The internal heat load is commonly composed of people heat gain, light, electronic equipment, mechanical/electrical equipment heat gain and other miscellaneous sources of heat gain such as process steam, etc. Each of these loads are calculated on an hourly basis for two-day types representing repetitive events for the whole year. Daytype (1) represents all working weekdays (approximately 251 days) and daytype (2) augments all weekends and holidays (approximately 114 days) to include 10 official holidays. The number of persons occupying the room, kilowatt rating of electrical, electronic equipment and lights are listed every hour for 24-h. Since some of the data collected under this internal load calculations section are considered "best" estimates, with varying degrees of accuracy, it was decided that the total equivalent temperature difference method, TETD, previously described under II-B is in fact an adequate methodology. No transient effects are considered for internal heat loads due to people, light equipment and hourly values were assumed causing quasi-steady state effects.

F. Architectural Data

The architectural and physical characteristics of the building (or zones) under study play an essential role in the first load calculation step. The data include building orientation,

latitude, elevation, wall areas, glass areas, space volume, physical dimensions, outside wall solar absorptivity and the cross section description of layers constituting walls and roofs. The data are grouped by zone; the maximum number of zones per building is not allowed to exceed 8 in the program. If there are more than 8 zones, grouping of several zones into macro-zones having the same fan-coil (air handler) arrangement may be done.

G. Shading Effects

Shading due to overhangs, side projections or adjacent buildings is handled in ECP as a fraction between 0 and 1 given by the user based on average shading conditions. The shading factors are used to attenuate the solar radiation falling on particular wall(s) of the zone under study. To reduce the manipulation process, various analytical methods used to compute the shaded areas, and their variations with hour of the day or sun's angles were not considered in ECP.

H. Loads Due to Neighboring Areas

The effect of a neighboring zone kept at a temperature different from that of the zone under study has been taken into consideration in ECP structure. However, ground floors were not included and were assumed always well insulated with no heat exchange to or from a basement zone.

I. Fan-Coil (Air Handler) Type and Arrangements

There are nine types of air handler arrangements that have been incorporated into ECP as illustrated in Fig. 1. These are: (1) single cold duct with terminal reheat at the zone, (2) dual duct multizone with mixing boxes or single duct multizone with mixing hot/cold air at the air handler section, (3) single cold duct with bypass control around the cooling coil and terminal reheat at the zone, (4) heat pump with bypass control, or single duct with alternately operating cooling and heating coils with bypass control, (5) two-level room (plenum and comfort air) with cold plenum air and comfort air modulated with terminal reheat, (6) two-level room with cold plenum air and comfort air modulated by a mixture of cold air with by-passed mixed air and terminal reheat, (7) two-level room with cold plenum air and comfort air modulated by mixing cold and hot decks, (8) single cold duct with fixed by-passed return air with terminal reheat and (9) two-level room with constant volume cold plenum air and variable volume comfort air at fixed hot deck temperature. For each building, the maximum number of air handlers allowed is 10. The simulation of air handler configurations is the second step of calculations. The ratio of outside air to total circulating air and the setpoint temperatures of both cold and hot decks are required as input. Also, for two-level rooms the maximum allowable plenum air temperature and the ratio of comfort air

discharge to total air discharge are required from the user. ECP also uses outside air economizer systems with various flow and temperature control mechanisms.

J. Time Clocks

The inclusion of time clocks in air-conditioning systems to control the operation (on or off) of air handlers has been presented as an energy saving suggestion. The energy saved by a time clock control is optimum for buildings that operate on the regular 8:00 a.m. to 5:00 p.m. schedule. The time clock on/off control is not applicable to light bulbs or electronic equipment since these will directly appear under the internal load schedules data.

K. Primary Equipment Performance

The user will identify under this heading: (1) the type or heating or reheating systems (electric, gas-fired or heat pump), (2) the arrangement of air handlers with the electric driven compressor/chillers (vapor compression refrigeration units) and (3) compressor stages and sizes. The maximum number of compressors is 10 and each compressor is allowed to be made of two stages with the second stage giving the full unit tonnage when on. Electric heaters (or boilers) were assumed having a constant 80% efficiency at all loads. The coefficient of performance of heat pumps and the vapor compression refrigeration cycle were assumed as a fraction (~50%) of the ideal Carnot's working between the refrigerant's evaporator and condenser temperatures. Partial-load performance was assumed unchanged from 100% full load until 40% of the full load. Beyond the 40% full load limit, the electric energy consumed in refrigeration units or heat pump units was assumed constant.

L. Energy Consumed by Auxiliary Equipment

Auxiliary equipment are defined in ECP as that equipment outside the air-conditioned zone space, which is necessary for building operation but does not affect the heating and cooling load calculations. Auxiliary equipment includes air handler fans, condenser fans (air cooled), condenser pumps (water cooled), boiler pumps, building external lights, etc. The energy consumed by this equipment directly affects the watt-hour meter reading. Their load profile and schedule can be quite complex, and their consumption is modeled in ECP by name-tag capacities only. For all pumps or fans, no allowance was made for partial load performance, or flow pressure and discharge variations.

M. Energy Cost

The unit cost of both thermal and electric energy as purchased from a utility company or generated on site is used to estimate the monthly or yearly cost of energy consumed.

In addition to the above component description, many default values are assigned to fill unknown input data. The program is written in FORTRAN IV computer language using the EXEC-8 codes of UNIVAC-1108 machines at JPL. The program output results include: (1) input data "echo" for the user to see all the entered data in tabulated forms, (2) diagnostic messages, (3) itemization of zones heating/cooling loads, per hour for the two-day type and for each month, (4) air handler and primary equipment energy consumption each hour for the two-day types and for each month, (5) hourly supply air temperature to each zone, (6) maximum and minimum air temperature supplied to each zone per month per year, (7) final equilibrium room temperature, (8) mixed air temperatures at the air handler, (9) peak hourly heating and cooling loads per zone, (10) peak hourly heating and cooling loads per primary equipment, (11) summation of monthly and yearly energy consumption and cost. For newly constructed buildings, the program also prints the design cooling tons of refrigeration, the design supply air discharge and the design outside air to circulating air ratio needed for ventilation.

III. Flow Chart

Fig. 2 illustrates briefly a block diagram of ECP. Each block depicts one phase of the ECP program: (1) input data, (2) ECP computations, (3) design considerations and (4) output. The subtitles in each block give the reader a general idea about the sequence of events within each phase of the ECP program.

The program documentation package includes user instructions for entering data, detailed flow charts, algorithm descriptions, input/output format and a solved example for illustration. The user would expect a cost of CPU time of approximately \$5/building zone, excluding printing cost. In this regard the program is considered inexpensive compared to other comprehensive codes, such as NASA's NECAP which costs approximately 200 times the cost of ECP. The accuracy of ECP, on the other hand, has been found very reasonable for engineering purposes, since predicted energy consumption values are only off the watt/hour meter values by a very narrow margin ($\pm 10\%$). This margin was tested at Goldstone Complex with zones that vary in number from one to fifteen per building.

References

1. *Technical Guidelines for Energy Consumption*, Final report No. AFCEC-TR-TI-12 for period Dec. 75 — March 77. Published Buildings Environmental Div., NBS Dept. of Commerce, Washington, D. C.
2. Chen, S. Y. S., "Existing Load and Energy Programs," *Heating-Piping and Air Conditioning*, December, 1975, pp. 35-39.
3. American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) *Handbook of Fundamentals*, 1972.
4. Threlkeld, J. L., *Thermal Environmental Engineering*, Prentice-Hall Inc., New Jersey, 1962.

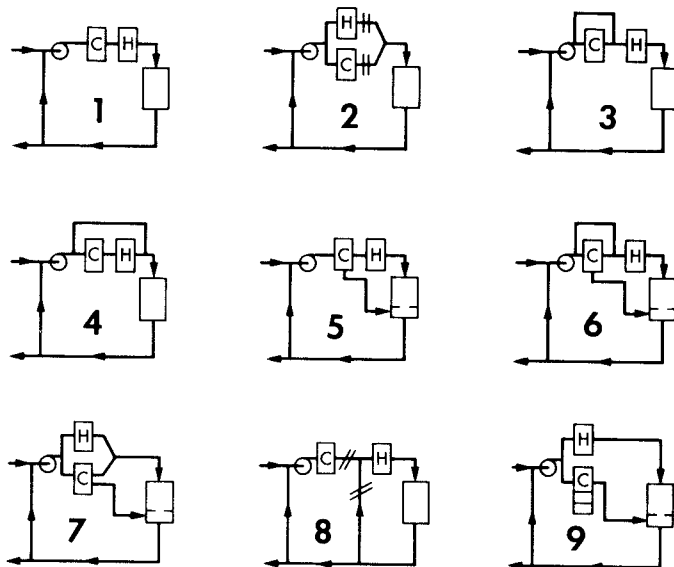


Fig. 1. Schematic of 9 air-handler-type arrangements

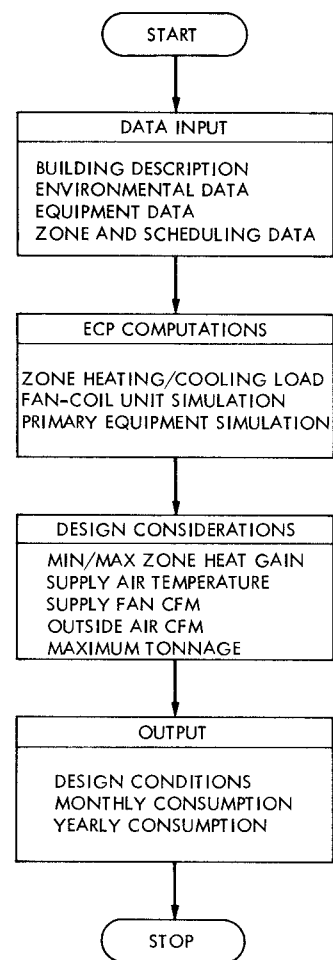


Fig. 2. ECP block diagram